RS-485 Crash Course Part 1: Basics

Understanding the basic principles of RS-485 is vital to selling microcontrollers (MCU) in industrial networking and automotive applications.

RS-485 is a wired digital interface developed for transmitting serial binary data over long distances. The interface uses differential signaling over twisted-pair cable to provide high immunity to external noise, therefore, assuring reliable data transmission.

Part 1 of this mini-tutorial provides the basics of an RS-485 interface and its components, covering the items listed below.

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1. RS-485 Components

The simplest form of an RS-485 interface is a data link between a transmitter or driver (D) and a receiver (R), as shown in Figure 1. The transmission medium is a twisted-pair cable whose receiver end is terminated with a termination resistor (R_T).

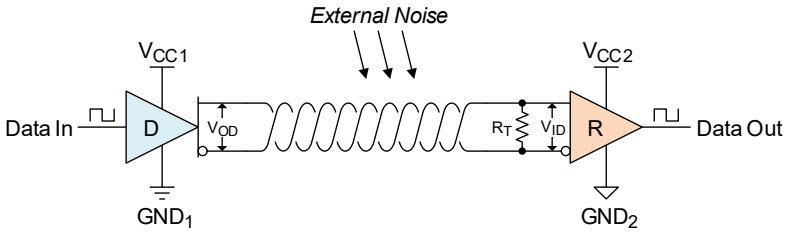

Figure 1. Simplest RS-485 Data Link

1.1 RS-485 Driver

The driver converts CMOS/TTL logic levels at its input (DI) into differential output voltages of $V_{OD} \geq \pm 1.5V$.

The driver has a non-inverting output (Y), which is in phase with the input, and an inverting output (Z), which has the opposite phase of Y and, therefore, DI. The output voltage is defined as $V_{OD} = V_Y - V_Z$. Therefore, if $V_Y > V_Z$, $V_{OD} \geq +1.5V$, and if $V_Y < V_Z$, $V_{OD} \leq -1.5V$.

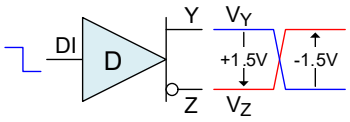

Figure 2. Level Shifting from Logic to RS-485 Levels

1.2 Receiver Input Voltage Levels

The receiver is a comparator, detecting differential input voltages ($V_{ID} = V_A - V_B$) from as small as ±0.2V and converting them into CMOS/TTL logic levels at its output (RO).

The receiver has a non-inverting input (A) that is in phase with the output (RO) and an inverting input (B) that has the opposite phase of RO. If $V_{ID} \geq +0.2V$, RO = High. If $V_{ID} \leq -0.2V$, RO = Low.

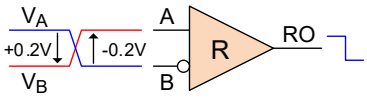

Figure 3. Level Shifting from RS-485 to Logic Levels

Two important points to remember:

- The receiver operates by detecting only the voltage difference between the inputs while disregarding any common-mode voltages, which are voltages shared by both inputs with respect to the receiver ground.
- The large difference between the ±1.5V driver output and the ±0.2V receiver input sensitivity provides high immunity to external noise disturbances.

To understand the driver and receiver operation better, read *TB506: Functional Principles of RS-485 Drivers and Receivers*.

1.3 RS-485 Cable

The transmission cable in RS-485 is of the shielded or unshielded twisted-pair type with a characteristic impedance of Z_0 = 120Ω. Twisted-pair cable has the advantage that each conductor is equally exposed to external noise when running through an electrically noisy environment. This feature ensures that each conductor possesses the same noise-induced voltage (common-mode noise), which is rejected by the differential receiver.

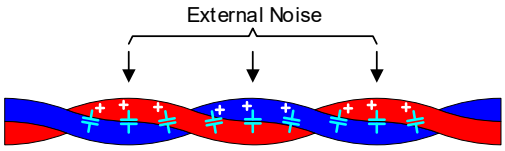

Figure 4. Twisted-Pair Cable Creating Common-mode Noise

1.4 Termination Resistor, R_T

RS-485 requires a termination resistor at the cable end opposite the driver that absorbs the energy of the traveling signal wave. The resistor value should match the characteristic cable impedance: $R_T = Z_0$.

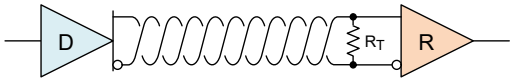

Figure 5. Location of the Termination Resistor

If the cable is not terminated, the signal at the cable end is reflected to the driver, interfering with the driver output signal, causing data errors. Figure 6 depicts a bus signal for the terminated and unterminated cases.

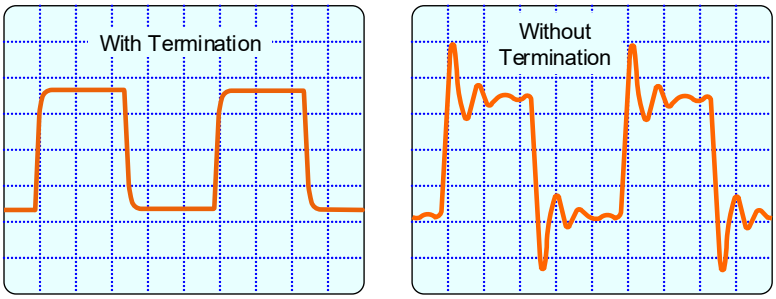

Figure 6. Bus Signal for a Terminated and an Unterminated Cable

2. Transceiver Types

An RS-485 network has one dominant bus node known as master. This master node exchanges data with multiple slave nodes, requiring every bus node to transmit and receive data. Although it is possible to perform these functions through single driver and receiver devices, from a manufacturing point of view, it proved more effective to combine both transmitter and receiver functions into a single device, known as a transceiver.

There are two types of transceivers, half-duplex transceivers (Figure 7) and full-duplex transceivers (Figure 8).

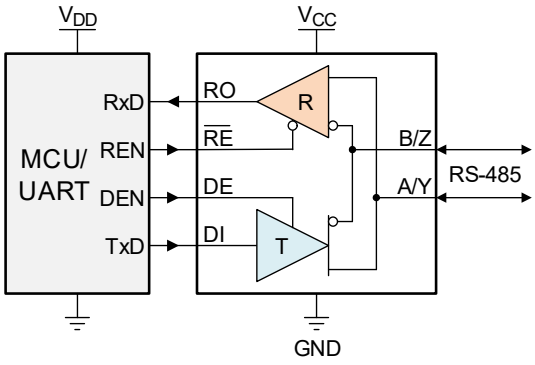

Figure 7. Half-Duplex Transceiver

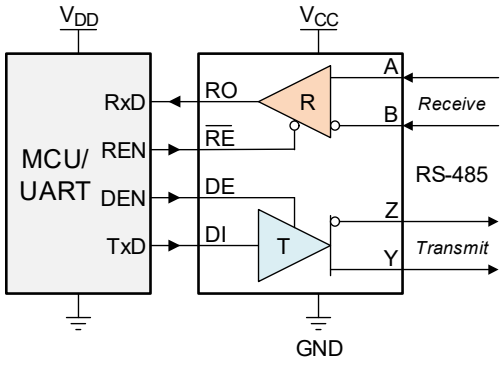

Figure 8. Full-Duplex Transceiver

Both transceiver types allow separate control of their transmit and receive functions through dedicated Enable inputs.

A logic Low at the receiver enable pin (/RE) activates the receiver, which converts the differential at the receiver inputs into logic levels at the receiver output (RO). A logic High at /RE disables the receiver and RO becomes high-impedance.

A logic High at the driver enable pin (DE) activates the driver, which converts the logic levels at the driver input (DI) into RS-485 signals at the driver outputs. A logic Low at DE disables the driver, making the driver outputs high-impedance.

As the half-duplex transceiver has its driver outputs internally connected to the receiver inputs, the device can transmit or receive data, but not simultaneously.

However, the full-duplex transceiver can transmit and receive data simultaneously, allowing higher data throughput.

3. Network Applications

An RS-485 network has one dominant bus node, the master node, that exchanges data with multiple slave nodes. The master node always initiates a data transfer. A slave node receives data from the master and, if commanded, responds to the master. Therefore, a data exchange constitutes a bidirectional communication requiring each bus node to receive and transmit data. Because each bus node includes a driver function, RS-485 is known as a multi-driver or multi-point bus.

3.1 Half-Duplex Bus Network

A half-duplex bus is a network where the master node transmits or receives data, but never simultaneously. This bus requires only one signal pair of transmission cable, commonly applied to long-distance networks of up to 4000ft (1200m) at data rates of up to 100kbps (Figure 9).

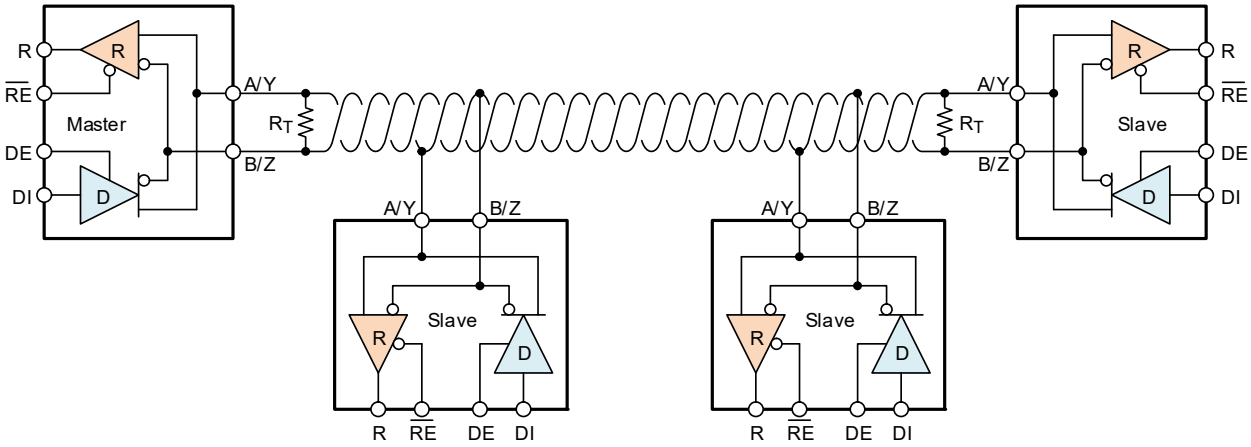

Figure 9. Half-Duplex Bus used for Long Distance Networks at Low Data Rates

Typical applications of half-duplex networks are often used on the factory floors of industrial automation systems and in HVAC, Lighting, and escalator networks of commercial building automation systems.

3.2 Full-Duplex Network

In a full-duplex network, the master node can transmit and receive data simultaneously, significantly increasing data throughput. However, this bus requires two signal pairs, which makes cabling efforts over long distances too expensive. Its application is, therefore, limited to short-distance networks of up to 100ft (30m) in length and data rates of up to 50Mbps (Figure 10).

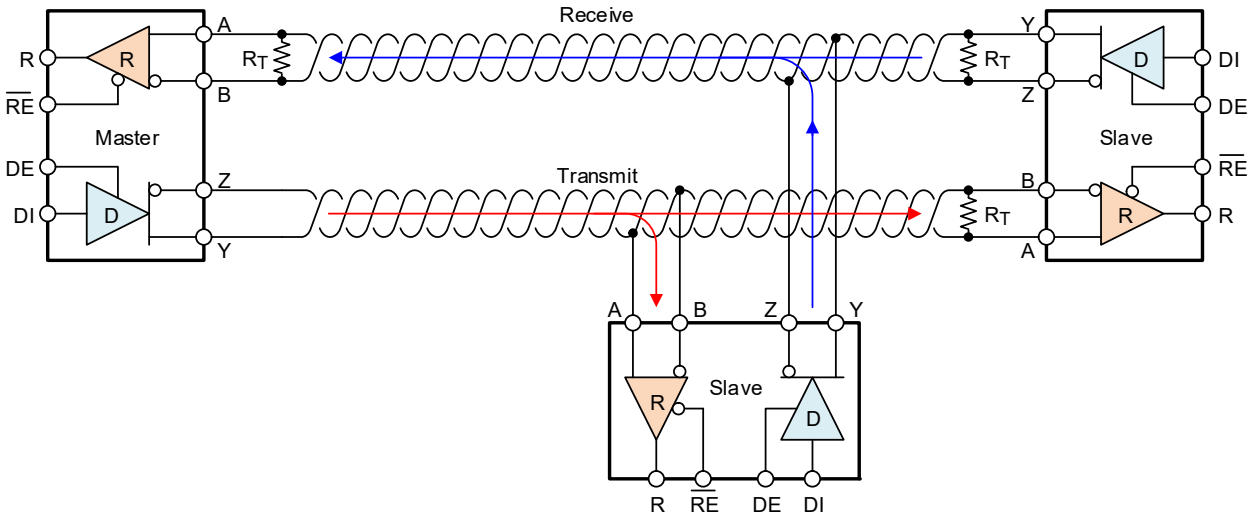

Figure 10. Full-Duplex Bus used for Short Distance Networks at High Data Rates

Typical applications of full-duplex networks can be found in industrial Robotics, Seismic Mesh networks, and base stations of mobile networks.

4. Conclusion

- RS-485 can support many bus nodes, either at low data rates over long distances or high data rates over short distances.
- Its transmission method using differential signaling over twisted pair cable makes it highly immune to external noise and ground-potential differences.
- The simple design structure of its transceivers combined with simple cabling efforts ensures that RS-485 has the lowest implementation cost amongst industrial interfaces.
- As the RS-485 standard only defines the electrical (physical layer) characteristics of its drivers and receivers, RS-485 components are open to various higher-level software protocols.

Part 1 presented the basics of RS-485 networks and their components.

Part 2 explains the key parameters designers consider when selecting RS-485 transceivers for certain network applications.

5. Revision History

Revision	Date	Description
1.00	Jun 21, 2023	Initial release.

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